NAVAL HEALTH RESEARCH CENTER

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J. H. Heaney

M. J. Buono

J. A. Hodgdon

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NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CA 92186-5122

BUREAU OF MEDICINE AND SURGERY (M2)
2300 E ST. NW
WASHINGTON, DC 20372-5300

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Naval Health Research Center
San Diego, California

Jay H. Heaney
Michael J. Buono[1]
James A. Hodgdon

[1]San Diego State University
San Diego, California

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INTRODUCTION

We have previously reported that in lieu of the more common end-of-test criteria such as core temperature < 39°C, and heart rate (HR) < 180 bpm (2,3), volitional fatigue for men exercising in the heat appears to occur with a reduction in stroke volume (SV) to a value of approximately 75 ml/beat/min (1). Since it has been established that females have a lower absolute SV (4) it is doubtful that a terminal stroke volume (TSV) of 75 ml/beat/min would be observed in females. It was hypothesized that using either body surface area (BSA), which would account for an increased peripheral blood circulation and the exchange between the skin and the environment, or fat free mass, which represents the body mass to be perfused would provide a physiological metric to normalize SV results between males and females. Additionally, we observed that while the use of a microclimate cooling garment (ice vest) attenuated the rate of cardiovascular drift, the fall in terminal SV (TSV) was independent of temperature and ice vest usage for males exercising in the heat. This paper provides results from a comparison evaluation of male and female SV responses to exercising in the heat both with and without the use of microclimate cooling.

MATERIAL AND METHODS

This research was conducted in compliance with all Federal regulations concerning the protection of human subjects. Fourteen males (24 ± 5 yrs; 1.94 ± 0.1 m^2; 17.3 ± 4.5 % fat; 49.2 ± 4.5 ml/kg/min VO_{2max}) and seventeen females (24 ± 4 yrs; 1.71 ± 0.1 m^2; 30.6 ± 4.8 % fat; 43.9 ± 6.5 ml/kg/min VO_{2max}) provided written consent. Upon completing an eight day acclimation protocol each subject underwent duplicate heat exposure trials once wearing an ice vest (V) and once without (NV) in three different thermal environments (A = 43°C and 48% RH; B = 51°C and 33% RH; and C = 57°C and 25% RH) for a total of six heat exposure trials. During each heat trial the subjects alternated approximately 20 min of treadmill walking (3mph, 3% grade) with 40 min of seated rest for six hours or until volitional fatigue. The microclimate cooling garment for this study was the Steele ice vest which contains six gel packs placed in three horizontal pouches across the chest and back region. The ice packs were frozen at -29°C and replaced every 120 min in environment A and every 90 min in environments B and C. The ice vest has a total weight of 5.1kg and a total cooling capacity of 270 watt/hr. Heart rate (HR), and rectal temperature (T_{re}), were measured every min throughout the heat trial. Cardiac output (CO) values, determined using the indirect Fick CO_2 rebreathing technique, were assessed approximately 7-10 min into each exercise session and provided a SV value. TSV results were evaluated as absolute values, adjusted for BSA (TSV/BSA), and adjusted for lean body mass (TSV/FFM). Menstrual phase was not controlled, however post-hoc blood analysis revealed that female subject participation during the follicular and luteal phase was evenly distributed.

RESULTS

Since there were several subjects who were able to complete the full 6-hours in the A-environment ice vest condition (mean = 5.5 hours), the physiological results from this trial did not represent a volitional fatigue effort and therefore, were not included in the analysis. End-of-test values for T_{re} (°C), HR (bpm), CO (L/min), TSV (ml/beat), TSV/BSA (ml/beat/m^2), TSV/FFM (ml/beat/kg), and stay time (min) were analyzed for effects of gender using a repeated measures ANOVA. Physiological results for the 5 trials are displayed in Table 1 (males) and Table 2 (females).

Table 1. Male Physiological Results.

n = 14	**A** No-Vest	**B** No-Vest	**B** IceVest	**C** No-Vest	**C** IceVest
*T_{re}	38.7 ± 0.5	38.8 ± 0.5	37.8 ± 0.4	38.9 ± 0.4	38.4 ± 0.5
*HR	149 ± 12	147 ± 13	134 ± 18	153 ± 15	147 ± 15
*CO	11.5 ± 1.6	10.3 ± 1.8	10.6 ± 1.5	11.2 ± 1.7	11.0 ± 1.9
*TSV	78 ± 14	71 ± 16	80 ± 14	74 ± 13	75 ± 16
*TSV/BSA	40 ± 6	37 ± 7	41 ± 7	38 ± 7	39 ± 8
TSV/FFM	1.22 ± 0.2	1.10 ± 0.2	1.24 ± 0.2	1.16 ± 0.2	1.17 ± 0.2
*Stay time	162 ± 32	139 ± 24	340 ± 35	88 ± 22	242 ± 62

* = significant gender effect, $p < 0.05$.

Table 2. Female Physiological Results.

n = 17	**A** No-Vest	**B** No-Vest	**B** IceVest	**C** No-Vest	C IceVest
*T_{re}	38.9 ± 0.4	38.9 ± 0.4	38.5 ± 0.5	38.9 ± 0.4	38.9 ± 0.5
*HR	156 ± 17	162 ± 15	159 ± 15	161 ± 20	162 ± 14
*CO	8.9 ± 2.2	8.5 ± 1.4	9.3 ± 1.0	9.0 ± 2.0	9.0 ± 1.7
*TSV	55 ± 13	53 ± 10	59 ± 7	57 ± 15	56 ± 12
*TSV/BSA	32 ± 7	31 ± 5	34 ± 4	33 ± 8	33 ± 6
TSV/FFM	1.19 ± 0.3	1.13 ± 0.2	1.27 ± 0.2	1.21 ± 0.3	1.21 ± 0.2
*Stay time	184 ± 37	93 ± 26	240 ± 92	71 ± 6	168 ± 68

* = significant gender effect, $p < 0.05$.

Use of the ice vest resulted in stay times over twice as long as stay times with no-vest. In general, end-of-test T_{re} values were similar for males and females, however, end-of-test HR values for females were 13 bpm greater. As expected, higher CO and SV values were observed for males and are most likely associated with their greater body size compared to females. The absolute TSV values were significantly different ($p < 0.05$) between males and females. In fact male TSV values (76 ml/beat) were similar to the first SV (SV1) female values (73 ml/beat). While the absolute SV1 and end-of-test or TSV values were significantly different ($p < 0.05$), the qualitative response in SV was almost identical. The average SV1 value for females was 32% lower (108 vs. 73, male and female, respectively) while the average TSV value for females was 26% lower (76 ml/beat vs. 56 ml/beat, male and female, respectively). Since BSA was thought to significantly effect the circulatory response (via increased peripheral blood pooling) and therefore impact the drop in SV, absolute TSV values were adjusted for BSA. Although this adjustment attenuated the TSV difference (39 ml/beat/m^2 vs. 33 ml/beat/m^2, for males and females, respectively), female TSV values were still significantly lower ($p < 0.05$). In an attempt to further explain the TSV gender differences, TSV was next adjusted for FFM. The males in this study had a mean FFM of 66 kg vs. 46 kg for the female participants. Figure 1 shows that adjusting TSV for FFM eliminated all TSV gender differences ($p > 0.05$).

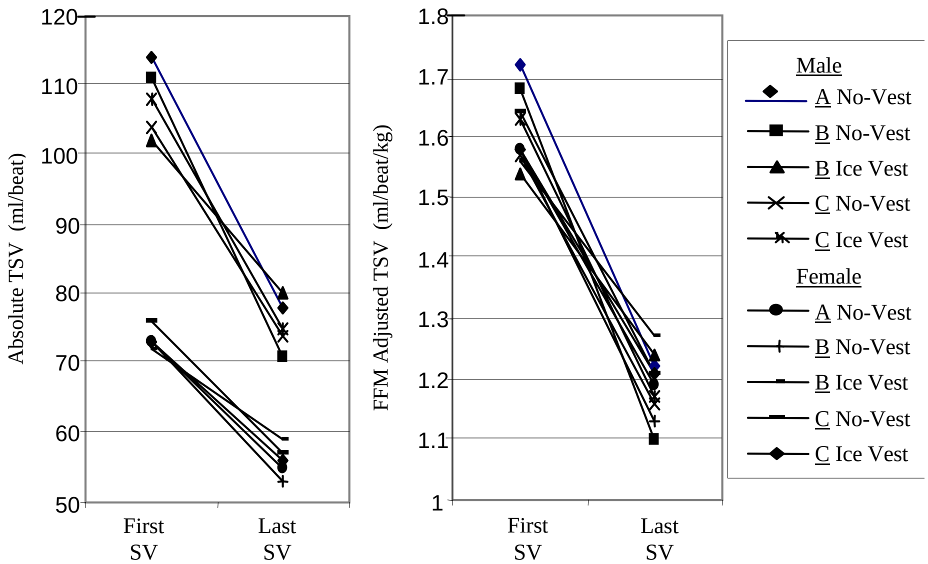

Figure 1. Absolute Terminal Stroke Volume and FFM Adjusted Terminal Stroke Volume Results

With respect to environmental, cooling, and gender conditions, Figure 1 supports the hypothesis that TSV is a valid indicator of volitional fatigue. Despite end-of-test T_{re} values < 39°C, and end-of-test HR values < 162 bpm, and stay times that ranged from 71 min to 340 min, the participants in this study terminated their heat exposure trial when TSV/FFM fell to approximately 1.2 ml/beat/kg.

CONCLUSIONS

Absolute terminal stroke volume was significantly higher in males. Adjusting terminal stroke volume for BSA reduced the magnitude of the gender differences in stroke volume but did not eliminate it. However, terminal stroke volume was identical for males and females when adjusted for fat free mass. Wearing an ice vest significantly increased stay times by more than twice the stay times without the vest and significantly delayed the fall in stroke volume. These results suggest that the limiting factor in maintaining an adequate stroke volume may be more closely associated with perfusion of the body mass as a whole rather than peripheral blood circulation at the skin surface.

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6. AUTHORS
Jay H Heaney, Michael J Buono, & James A Hodgdon

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Naval Health Research Center
P.O. Box 85122
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14. ABSTRACT (maximum 200 words)
We have previously reported that volitional fatigue for men exercising in the heat seems to occur with a reduction in stroke volume (SV) to approximately 70 ml/min. It is unknown, however, if these values are valid for women, particularly in consideration of their lower absolute SV and smaller body surface area (BSA). The SV responses of 14 male and 17 female, heat acclimated volunteers were compared. Their mean age and BSA were 23 and 24 yr, and 1.91 and 1.71 m2, respectively. Each subject alternated approximately 20 min of walking at 3 mph and 3% grade with 40 min seated rest in 43°C, 51°C, and 57°C ambient air temperature for 6 hours or until volitional fatigue. Duplicate trials at each temperature were conducted, once with and once without wearing a passive microclimate cooling (ice) vest. SV was measured during each 20-min exercise bout. The table below presents the mean SV data obtained at volitional fatigue in the vest condition (V) and no-vest condition (NV). SV was normalized using BSA in order to adjust for body size differences (peripheral blood pooling) between males and females. SV results differed significantly ($p<0.05$) between genders in all 3 environmental and both vest conditions (male SV values averaged 21 ml/min higher than for females). Adjusting SV by BSA still resulted in significantly higher values for males compared to females by an average of 6 ml/m^2/min. However, normalizing SV for lean body mass resulted in an identical terminal SV for males and females. Although males may have a higher terminal SV, adjusting for lean body mass appears to eliminate any gender differences in terminal SV. These results demonstrate that lean body mass may contribute more towards heat tolerance capacity than body surface area.

14. SUBJECT TERMS
thermoregulation, heat stress, microclimate cooling, stroke volume, cardiovascular drift

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